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Design and Homogenization of the Acoustic Metamaterial using the Boundary Field Averaging & Its Applications

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Abstract

In general, the design approach using the frequency response (e.g., S-parameters) is widely used in order to design the acoustic metamaterials (AMMs) [1]. On the other hand, this approach is very sensitive to the frequency response, and the acoustic energy loss due to resonance characteristic of the sonic crystal always exists. It is impossible to create the band-gap material and/or the self-collimating system based on the certain isofrequency contour (IFC) [2]. Thus, we propose the homogenization-based design approach in order to complement the limitations of this conventional approach. As the first step towards this goal, this paper proposes a homogenization of the acoustic metamaterial based on the Bloch-mode analysis. The equivalent/effective material properties (i.e., mass density tensor, bulk modulus, impedance, etc.) of the AMMs with an arbitrary shape can be extracted from the proposed homogenization. This method computes an averaged value of the Bloch-mode of the pressure and velocity fields. We need to homogenize the two equations (i.e., linearized Euler equation and continuity equation) by applying both "divergence theorem" and "gradient theorem" in order to compute the averaged values. As the second step, the proposed homogenization-based design sensitivity analysis is performed for the optimal design of the AMMs. Finally, we perform the size/shape/topology optimization using the proposed homogenization and design sensitivity analysis, in order to design AMMs with the certain specified equivalent/effective material properties (e.g., zero-index AMM). The proposed design approach is verified through the various applications (e.g., the omnidirectional loudspeaker system with a zero-index AMM, the acoustic lens system with a double negative AMM, the perfectly matched layer (PML)-based absorptive AMM, and the IFC-based self-collimator, etc.).

References

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